Advances in 3D Image Acquisition

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APPLICATIONS OF 3D IMAGING

- Diagnostic
  → Improved understanding of complex geometry
  → Measurement of volume
- Surgical/therapeutic (minimally invasive)
  → Planning
  → Implantation guidance
  → Monitoring procedures
  → Therapy follow-up

3D IMAGING TECHNIQUES

- 2D Ultrasound leading to 3D Ultrasound
- CT leading to Computed Rotational Angiography
- MRI leading to 3D MRI
- PET leading to PET/CT

3D ULTRASOUND REFERENCES

- Nelson TR, Downey DB, Pretorius DH, Fenster A. *Three-Dimensional Ultrasound*. Lippincott, Williams, and Wilkins, Philadelphia. 1999.
- Fenster A, Downey D, "Three-Dimensional Ultrasound Imaging". *Handbook of Medical Imaging, Volume I, Physics and Psychophysics*. Beutel J, Kundel H, Van Metter R (eds.). SPIE Press, Bellingham, Washington, p. 433-509, 2000.
- Fenster A, Downey D, "3-D Ultrasound Imaging". Annual Review of Biomedical Engineering - Vol. 2, 457-75, 2000.

LIMITATIONS OF 2-D ULTRASOUND

- 2-Dimensional
  → must build 3-D image mentally
  leads to inaccuracy & variability
- Spatial location uncertain

→ difficult to reproduce view
→ difficulties in quantitative follow-up
→ difficulties in surgical guidance

3-D ULTRASOUND: Approach

- Rapidly record 2-D images
- Anatomy
- Blood flow
- Rapidly reconstruct 3-D image
- View patient in computer
- Allow quantitative measurements

ACQUISITION GEOMETRIES

- Predetermined: Mechanical movers
  → Precisely known geometry
  → Internal or external to transducer housing

- Random: Free-hand localizers
  → Easy to use
  → Subject to errors
  → Reconstruction more difficult

ACQUISITION: Mechanical Movers

- Linear Scanning
- Tilt Scanning
- Rotational Scanning

LINEAR SCANNING

- Advantages
  →Parallel images _ reconstruction easy
  →Sampling easily optimized
  →Color Doppler _ geometry simple
- Disadvantages
  →Mechanically complicated translator

TILT SCANNING

- Advantages
  →Mechanically easy
  →Sector images _ reconstruction moderate

→Color Doppler _ geometry moderate

- Disadvantages
  →Undersampling / oversampling

ROTATION SCANNING

- Advantages
  →Mechanically easy
  →Small access window
- Disadvantages
  →Reconstruction difficult
  →Axis of rotation must be fixed

TYPICAL ACQUISITION TIMES

- Linear..... 5 -15 sec.
- Rotation ..... 12 sec.
- Tilting .....0.2 -10 sec.
- Power Doppler.....10 - 20 sec.
- Gated Color Doppler..... 30 - 90 sec.

FREEHAND 3-D SCANNING
ACQUISITION: Free-hand Localizers

- Acoustic Localizers
- Articulated Arm Localizers
- **Magnetic Field Localizers**

ACOUSTIC LOCALIZERS

- Advantages
  →Simple technology
- Disadvantages
  →Unobstructed line of sight
  →Correct for variation in speed of sound for temperature and humidity

ARTICULATED ARM LOCALIZERS

- Advantages
  →Simple technology
  →Can constrain motion
- Disadvantages
  →Restricted scanning region

→Errors propagate

MAGNETIC FIELD LOCALIZERS

- 6 DOF magnetic field sensor
- Receiver on transducer
- Transmitter beside the patient
- Measure spatially varying magnetic field
  → Position
  → Orientation

MAGNETIC FIELD LOCALIZERS

- Advantages
  →Simple to use
- Disadvantages
  →Electromagnetic interference
  →Distortions due to ferrous metals
  →Scanning gaps

SURGICAL/INTERVENTIONAL OPPORTUNITIES

- 3D ultrasound-guided biopsy
  →Breast, Prostate, Liver
- Minimally invasive surgery / therapy
  →Prostate, liver, breast, brain
  →Radiation, brachytherapy, cryotherapy, photocoagulation, PDT, hyperthermia

3D ULTRASOUND GUIDED PROSTATE BRACHYTHERAPY

- PROSTATE SEGMENTATION
- CORONAL VIEW**: needle angled medially**
- NEEDLE: Coronal View
- CORONAL & SAGITAL VIEWES
- BRACHYTHERAPY**: needle path**
- BRACHYTHERAPY**: 20 seeds**
- BRACHYTHERAPY**: post-implant**
- **3D CT & US post Brachytherapy**

3D US PROVEN ADVANTAGES

- Rapid scan
- Improve repeatability & accuracy

- Improve volume measurements
- Access new imaging planes
- Improve therapy planning & guidance

FUTURE 3-D ULTRASOUND

- Semi-automatic segmentation and measurements
- Interactive and intuitive volume viewing
- Couple hand / instruments to image for use in surgery, therapy, biopsy
- Real-time 3D US

COMPUTED ROTATIONAL ANGIOGRAPHY (CRA)
or CONE BEAM CT

- Fahrig, Moreau, Holdsworth *Med Phys* 24, 1097-1106 (1997)
- Fahrig, Holdsworth *Med Phys* 27: 30-38 (2000)

CANDIDATE IMAGING TECHNIQUES

- Spiral CT
  →patient access, fluoroscopy
- MRA
  →resolution, patient access, fluoroscopy, flow artifacts
- Gantry-mounted XRII
  →patient access, range of view angles, cost
- *C-arm mounted XRII*

CRA: introduction

- modify conventional DSA system to acquire projections around object
- ideal for high-contrast imaging
- applications for CRA: diagnostic angiography, interventional imaging
- acquire x-ray projections in ~ 6 s with intra-arterial injection

C-ARM BASED 3D CT: CRA

- 4.4 s acquisition at 45°/s
- 30 Hz frame capture, resulting in 130, 512 x 512 images over 200°
- 400^3 volume reconstruction with 0.40 mm voxels (16 cm cube)
- Ideal for high contrast imaging,
  →e.g. 6 s internal carotid injection; 3 ml/s for 18 ml total (300 mg/ml iodine)

C-ARM BASED 3D CT

- advantages:
  - → improves visualization, quantification of diseased vessels
  - → compatible with existing DSA system (fluoroscopy, complex view angles)
- problems:
  - → XRII geometric distortion
  - → non-ideal gantry motion
  - → artifacts (limited views, inconsistent views)

XRII Distortion

- Image intensifier exhibits warp, rotation, translation
- Distortion is function of angle with earth's magnetic field
- Can be corrected with image post-processing

LONG-TERM GANTRY STABILITY

- Gantry is stable over several months
- Correction reduce non-ideal motions to ~ 0.05 mm

C-ARM BASED 3D CT

- C-arm based cone-beam CT scanner
- 4.4 s acquisition at 45°/s
- 30 Hz frame capture130, 512x512 images over 200°
- 400^3 reconstruction with 0.40 mm isotropic voxels (16 cm cube)

METHODS: Acquisition parameters

- Helical CT:
  - → 120 kVp, 155 mAs
  - → 0.3 x 0.3 x 1 mm (nominal) voxel spacing
  - → 10 cm S/I coverage
- Cone-beam CT:
  - → 90 kVp, 75 mAs
  - → 0.4 x 0.4 x 0.4 mm isotropic voxel spacing
  - → 16 cm S/I coverage
- Summary: Decreased slice thickness for cone-beam CT

RESULTS: Dose

- Helical CT:
  - → average entrance exposure 3.8 cGy
  - → average effective dose 1.46 mSv
- Cone-beam CT:
  - → average entrance exposure 0.9 cGy
  - → average effective dose 0.36 mSv

- Summary: Cone-beam CT reduces dose by factor of 4

RESULTS: Noise

- Helical CT:
  → average image noise ± 29 HU
- Cone-beam CT:
  → average image noise ± 116 HU

● Summary: Cone-beam CT increases noise by factor of 4
RESULTS: Conebeam vs helical CT
RESULTS: Conebeam vs helical CT